

Water as Focus of Problem-Based Learning: An Integrated Curricular Program for Environmental Education in Secondary School*

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In this paper, we explore some aspects regarding the introduction of an active learning approach to deal with environmental issues in secondary school during natural sciences lessons. Integrated curricular program and PBL (problem-based learning) are comprehensive approaches designed to engage students in investigation of authentic problems. We used a scenario regarding water as a socio-environmental issue to introduce the hydrosphere curricular topic. Two different ways were used for the presentation of the scenario. Here, we present students' and teachers' perceptions about the PBL approach, as well as students' ideas about water proposed in both cases. Discussion among students was more active, when less input was given. Even though some difficulties arose, PBL approach was appreciated by the majority of students and teachers.

Keywords: environmental education, integrated curricular program, PBL (problem-based learning), active learning, secondary school, water

Introduction and Objectives

Sciences teaching process in secondary school should not ignore important environmental and health issues to be taught. We usually include these issues in what we call education ecology, education for sustainability, environmental education, health education and their synonymous. We believe that these important issues have to be integrated in the secondary school natural sciences programme and, indeed, that they can be used to stimulate interest of students when introduced at the beginning of a science module. Such an approach could lead students to learn about both curricular and environmental and health topics, integrating them together (Gutiérrez & Pirrami, 2009a, 2009b; Pirrami, 2010).

The general aim of this study is to explore the best way to adopt the ICP (integrated curricular program) model (Sharpe & Breunig, 2009) and the PBL (problem-based learning) method to integrate environmental issues with curricular scientific topics, and at the same time, to increase students' interest, motivation and awareness towards scientific and environmental matter, at the level of compulsory secondary schools. In this research, we

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explore two ways for introducing the hydrosphere curricular topic by a PBL scenario regarding water.

The main questions of this research are as follows:

- (1) Would ICP be an effective model to integrate environmental issues with science curricular topics?
- (2) Would PBL be an effective method to develop students' autonomy and abilities?
- (3) Would ICP/PBL be appreciated by students and teachers?
- (4) Which could be the best way to present the scenario, within the ICP model, to introduce a curricular topic starting from an environmental issue at the secondary school level?
- (5) Which could be the best way to develop the teaching/learning module with the PBL approach to increasing students' interest and engagement during secondary sciences lessons?

In this paper, we will concentrate on questions three to five as for the first two ICP and PBL should be experimented several times by the same students and with different curricular and environmental topics.

Framework

Science education should include information about processes and consequences regarding environmental and health issues to let everyone have tools and knowledge in order to adopt correct behaviours. School must give this information in a way that enables students to reason on processes and discover consequences, but not just preach what is good or not good for their and environmental health. Science teachers should have a special concern about these issues, because they are strictly linked to life and earth sciences topics. However, in our experience with secondary school we noted that most of time these issues are not covered during traditional lessons or they are taught marginally and normally at the very end of a learning module.

Some of the important reasons to incorporate environmental and health issues in the natural sciences program are ethical ones. However, if we just look at the economical aspects, a person who is healthy and respectful for the environment and for his/her health represents a lower cost for the society. Moreover, as proposed in the Biophilia hypothesis (Wilson, 1984; Kellert & Wilson, 1993) and in Frumkin's nature theory (2001), the natural environment influences human well-being. On the other hand, human activities influence ecosystems health, and nowadays, this is truer than that in the past, both at local and global level. Thus, ecosystems health and human well-being are strictly interconnected and environmental quality results in an important aspect for preserving people's health.

How should we deal with environmental issues within the natural sciences curriculum?

Natural sciences teachers should re-think the teaching and learning process, so that students are enabled to apply scientific knowledge to the understanding of complex socio-environmental issues. This would support students' ability to develop critical and reflective skills which in turn lead to awareness and responsible actions towards the environment (Colucci, Camino, Barbiero, & Gray, 2006; Colucci, Gray, Marchetti, & Camino, 2007). If teachers use an active learning approach, it is more likely that students will develop these critical and reflective skills.

Experiences in school show that students have little ability for analysis. Rarely do they ask themselves questions and use mainly their mnemonic abilities instead of reasoning. According to "Bologna declaration" and to life-long learning concept, schools should train students to be aware of the need to improve their knowledge and abilities as well as give them the instruments they need to do that autonomously. "Lisbon strategy" has a special concern about science education and the high level group on science education of the European Commission (Rocard, Csermely, Jorde, Lenzen, Walberg-Henriksson, & Hemmo, 2007) recommends a

“reversal of school science-teaching pedagogy from mainly deductive to inquiry-based methods” which also because they “provides the means to increase interest in science” (p. 5).

In this research, we use an ICP approach to dealing with traditional curricular science topics integrated with environmental issues, in other words, with the ICP approach; environmental problems can be used to take students into the more traditional life or earth sciences topics. As an alternative learning approach, ICP respond to a number of critiques lodged against the traditional educational model in terms of its limitations in fostering environmental citizenship. The main argument refers to separation of science contents into discrete disciplines that would leave little opportunity to address the complex problem of environmental education. This allows a more interdisciplinary study of the environment (Sharpe & Breunig, 2009). ICP aims to change from a fragmented and discipline-based approach in which subjects are taught as separate and distinct disciplines, usually by different teachers, into an attempt to blend complementary subjects into a more interdisciplinary investigation of complex topics, experiences or problems. This approach was also coherent with the necessity of taking students to the understanding of the complexity of the real word, which was a fundamental aspect of science education (Sanmartí, 2002) and would increase also students’ engagement in science (Osborne & Dillon, 2008).

Another reason that would suggest to stimulate secondary students by using different learning methods, in order to let them develop and maintain more diverse skills instead of relying only on mnemonic abilities, could be the neuroscience evidence regarding the pruning phenomenon in adolescent brain (Casey, Giedd, & Thomas, 2001).

We believe that PBL method (Barrows, 1998; Boud & Feletti, 1991; Kolmos, 2004; Rangachari, 2001; Woods, 1995) would facilitate this integration. Moreover, it would also increase students’ interest, participation and motivation, as well as increasing their ability to work in a team to look for information autonomously and analyse and synthesize texts, as they have to look for information by themselves and try to explain and/or give answers to the questions aroused by the given problem.

Problem-Based Learning

As shown by meta-analysis studies (Fernandez, García, de Caso, Fidalgo, & Arias, 2006; Mergendoller, Maxwell, & Bellisimo, 2006; Belland, French, & Ertmer, 2009; Walker & Leary, 2009; Ravitz, 2009), much of the contemporary literature on PBL is concerned with efficacy or with guidelines on design or implementation of this methodology in the classroom.

Barrows and Wee (2007) stressed that PBL should be a method which must be reiterated but not episodic, but, in the practice, it is often a part of an integrated curriculum, which use a systems-based approach, with mixed teaching methods (including PBL), whose aim is the achievement of learning outcomes, both in knowledge and skills. It can be used either as the mainstay of an entire curriculum or for the delivery of individual courses. When PBL is introduced into a curriculum, several other issues for curriculum design and implementation need to be tackled. PBL is generally introduced in the context of a defined core curriculum and integration of science topics. It has implications for staff and learning resources and demands a different approach to timetabling, workload and assessment. PBL is often used to deliver core material in a non-conventional review of the curriculum. Ravitz (2009) argued that it was important to consider the context for PBL use, including variations in PBL implementation. The effectiveness of PBL may depend on a variety of factors that influence the implementation and outcomes. These include the type of school environment and

conditions. For example, in a K-12 (from kindergarten through 12th grade) context it is important to know if PBL is used by individual teachers or as part of a larger school wide reform that is compatible with PBL (Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000; Pearlman, 2002). It is also important to identify the intensity and duration of PBL practices. In medical school, a three-year curriculum and testing cycle might be common. In contrast, K-12 teachers may devote only weeks or months to PBL, combining it with a variety of other instructional methods. Hoffmann and Ritchie (1997) argued that "Problem-based learning is a student-centred pedagogical strategy that poses significant, contextualized, real-world, ill-structured situations while providing resources, guidance, instruction and opportunities for reflection to learners, as they develop content knowledge and problem-solving skills" (p. 97). PBL is not a problem-solving technique per semester, rather it uses appropriate problems to increase knowledge and understanding.

Bridges (1992) outlined the main characteristics of PBL:

- (1) The starting point for learning is a problematic stimulus for which an individual lacks a ready response;
- (2) The problem is one that students are apt to face as future solutions;
- (3) The knowledge that students are expected to acquire during their training is organized around problems rather than disciplines;
- (4) Students, individually and collectively, assume a major responsibility for their own instruction and learning;
- (5) Most of the learning occurs within the context of small groups rather than lectures.

In PBL, students are guided by the problem case or scenario to define their learning objectives, and they study independently (self-directed learning) before returning to the group to discuss and refine their acquired knowledge. Paper-based PBL scenarios can form the basis of the core curriculum and ensure that all students are exposed to the same problems. Sometimes, the modified PBL techniques have been introduced into education, with controversial situation used as the stimulus for learning (Wood, 2003). As Walker and Leary (2009) argued, in PBL, scenarios relating to real life are used as a point of departure for the learning process. PBL is successful only if the scenarios are of high quality. The scenarios should lead students to a particular area of study to achieve the learning objectives (Dolmans & Snellen-Balendong, 1997). Some standard quality criteria to set up effective PBL scenarios within a integrated curricular program in secondary school curricula are the following (as cited in Dolmans & Snellen-Balendong, 1997):

- (1) Learning objectives defined by the students according to the scenario should be consistent with the school learning objectives;
- (2) Problems should be appropriate to the level of the students' understanding;
- (3) Scenarios should have sufficient intrinsic interest for the students or relevance to future practice;
- (4) Basic sciences should be presented in the context of a real scenario to encourage integration of knowledge;
- (5) Scenarios should contain cues to stimulate discussion and encourage students to seek explanations for the issues presented;
- (6) The problem should be sufficiently open, so the discussion is not curtailed too early in the process;
- (7) Scenarios should promote students' participation in seeking information from various learning resources.

Mergendoller et al. (2006) compared the effectiveness of PBL and traditional instructional approaches in knowledge and examined whether PBL was differentially effective with students, demonstrating different levels of four aptitudes: verbal ability, interest in subject, preference for group work, and problem-solving efficacy. Additional analyses provided evidence that PBL was more effective than traditional instruction with students of average verbal ability and below with students who were less confident in their ability to solve

problems. About the effect of discussion in a PBL approach, it has been demonstrated that students who could discuss on a relevant problem displayed more attraction to the subject, were more interested and more willing to attend a lecture of science than the students that not involved in such discussion. This finding seems to indicate that with the PBL approach, students were more engaged. Moreover, no relation could be found between the students' responses and their subsequent performances in a test, suggesting that intrinsic interest did not play an important role in the causal chain between treatment of a topic and performance related to that topic (Norman & Schmid, 1992, p. 558). Schmidt, Vermeulen, and Van der Molen (2006) found that knowledge acquired within a PBL context was maintained longer and used better.

Group learning, as Wood (2003) argued, facilitates not only the acquisition of knowledge but also several other desirable attributes, such as communication skills, teamwork, solving problem, independent responsibility for learning, sharing information and respect for others. PBL can therefore be thought of as a small group teaching method that combines the acquisition of knowledge with the development of generic skills and attitudes. Presentation of specific material as stimulus for learning enables students to understand the relevance of underlying scientific knowledge.

Methodology

PBL Process

A typical PBL process consists of a group of students (usually eight to ten) and a tutor, who facilitates the session. The length of time (number of sessions) that a group stays together with each other and with individual tutors varies between institutions. A group needs to be together long enough to allow good group dynamics to develop, but may need to be changed occasionally, if personality clashes or other dysfunctional behaviours emerge. Enough time should be allowed students to perform the self-directed learning required by the method. Suitable charts or a blackboard should be used for recording the proceedings. At the start of the session, depending on the trigger materials, either the student chair reads out the scenario or all students study the materials. Learning resources or learning materials might be handed out at appropriate times of the tutorials progress (Wood, 2003).

The teaching and learning process is defined by different authors (Dolmans & Snellen-Balendong , 1997; Wood, 2003; Walker & Leary, 2009; Strobel & Van Barneveld, 2009) and the several variations that exist all follow a similar series of steps: teamwork, chairing a group, individual listening, cooperative discussion, respect for colleagues' views, critical evaluation of the different points of view, use complementary resources and information to document the situation, and define a common skills into the group. According to Wood (2003), a typical PBL process consisted of the following steps:

Step 1: Identify and clarify unfamiliar terms presented in the scenario, and list those that remain unexplained after discuss;

Step 2: Define the problem or problems to be discussed. Students may have different views on the issues, but all should be considered. A list of agreed problems is reported;

Step 3: "Brainstorming" session to discuss the problem, suggesting possible explanations on basis of prior knowledge. Students draw on each other's knowledge;

Step 4: Review steps 2 and 3, and arrange explanations into tentative solutions;

Step 5: Formulate learning objectives. Group reaches consensus on the learning objectives. The tutor ensures that the learning objectives are focused, achievable, comprehensive and appropriate;

Step 6: Private study (all students gather information related to each learning objective);

Step 7: Group shares results of private study (students identify their learning resources and share their results). The tutor checks learning and may assess the group.

The role of the teacher in the class was to facilitate the process, helping the chair to maintain group dynamics and moving the group through the task, to ensure that the group achieves appropriate learning objectives in line with those set by the curriculum (Himelo-Silver & Barrows, 2006; Barron & Darling-Hammond, 2008). The tutor may need to take a more active role in step 7 of the process to ensure that all the students have done the appropriate work and suggest a suitable format to present the results of their private study. The tutor should encourage students to check their understanding of the materials. He/she can do this by encouraging the students to ask each other to explain topics in their own words or by the use of drawings and diagrams.

Application of ICP and PBL in secondary school classes need an adjusting of the method, because in each secondary class, there is only one teacher with up to 30 students. Moreover, during planning of the activities, some other aspects should be taken in account that they are not the same as those in the university: Teachers are normally available to use just a part of their time; students are not used to looking for information, analysing and synthesizing them autonomously; scheduled sessions sometimes cannot be carried out because of unexpected school activities.

Procedure Used in the Classroom

In our study, it was proposed to teachers from different Italian secondary schools to collaborate in this research. Six teachers from different technical schools agreed to dedicate two hours in four weeks to deal with scientific and socio-environmental issues, introducing it with an environmental scenario. During spring of 2008, we started working with six classes, a total of about 104 students, between 14 and 15 years old. The scenario regarded water supply with the aim to treat the module concerning hydrosphere, water in natural and human systems and the socio-environmental related problems. A PBL approach was never used before in these classes, and concepts about hydrosphere were not taught previously. Here is the scenario given to students:

In the little town Montalto, during last summer, water supply was interrupted several times. The town council asks us to prepare a booklet to be given to families in order to explain why it is important to save water and how to reduce its consumption in the houses. What would you write in the booklet?

In a C1 (first cluster) of three classes, students were given a text with the scenario, followed by a dialogue containing experts' perspective on how to deal with this issue, where concepts listed in Table 1 were explicit. In this cluster, within each class, students read the text and had to point out unknown words and identify from the dialogue the concepts considered to be important for the booklet. Then, there was a first discussion leaded by the tutor/researcher and the important concepts were listed on the blackboard. The information to be searched for was shared among small groups of up to four students, each group dealing with a different concept. Students look for information at home and, in the next session, they shared the information they found at the class level and another discussion took place, at the end, new assignments for next session were established. This happened for three times. At the end of the process, a further session to summarize the entire module was given by the teacher to help students prepare for the final test.

In a C2 (second cluster) of the other three classes students, was given a text with only the scenario without dialogue and keywords. Students had the time to think individually about the matter and write down concepts

they consider important to be treated in the booklet. Then the discussion at the class level took place and, different from cluster C1, all the students had to look for information about the same concepts. In the next session, they had to share the information firstly within a small group and then at the class level. The rest of the procedure remained the same as for cluster C1.

Table 1

Concepts About Water From the First PBL Session

Concepts regarding water	Cluster C1				Cluster C2			
	Class 1	Class 2	Class 3	Percentage (%)	Class 4	Class 5	Class 6	Percentage (%)
Pointed out by students of the different classes								
Where water can be found in the Earth and in which form	X	X	X	100	X	X	X	100
The cycle of water	X	X	X	100	X	X	X	100
Rocks and water tables	X	X	X	100	-	-	-	0
Springs and wells	X	X	X	100	-	X	X	66.66
Water uses	X	X	X	100	X	X	X	100
Water pollution sources and consequences	X	X	X	100	X	X	X	100
Purification plant and process	X	X	X	100	-	X	X	66.66
Drinkability and supply of water in the houses	X	X	X	100	X	X	X	100
Tap water vs. bottled mineral water	X	X	X	100	-	X	-	33.33
Why water is important for living organisms	X	X	X	100	X	X	X	100
“Blue gold” water as a precious resource	-	X		33.33	X	X	X	100
Conflicts due to water	-	X	X	66.66	-	X	X	66.66
Techniques for saving water in the houses	X	X	X	100	X	X	X	100
Water availability and consumption in different countries	-	-	-	0	X	X	X	100
Water waste in non-domestic uses and possible solution	-	-	-	0	X	X	X	100
Number of concept pointed out in each class	11	13	11		10	14	13	
Percentage of concept pointed out in each class (%)	73.33	86.66	73.33	77.77	66.66	93.33	86.66	82.22
Minimum number of concepts given by a single student	5	3	4		2	3	2	
Maximum number of concepts given by a single student	10	13	11		7	10	6	

Concepts regarding water considered important by students were recorded for classes of both clusters and observations about students' participation in the discussion were made.

At the end of the process, we interviewed teachers and gave questionnaires to students, to assess their perceptions about the PBL approach. The questionnaire includes both multiple choice and open-ended questions. The answers to the latter type of questions were analysed and grouped, regarding the same concept.

Results and Discussion

The researcher's observations could not always be noted in a systematic way, as the researcher acted both as a tutor and an observer. Nevertheless, some aspects were jotted down during the teaching/learning process, and were also confirmed during the interview with teachers. Of course, the comparison between C1 and C2 could be made only according to the researcher's observation, as he was the only one that was present in all classes.

By this comparison, we could observe that, during the first session, in classes of cluster C1, the discussion

among students about the important aspects regarding water was less participated than in classes of cluster C2. This happened probably because C1 students could already found explicit key concepts in the dialogue. On the other hand, in C2, even if a single student wrote down a lower number of key concepts if compared with C1, almost all the concepts could come out during the more active discussion (see Table 1). This could lead to say that when students are given more autonomy, they are more engaged and more participating, and this is confirmed also by students' opinion (see Table 2). In general, participation and engagement are considered higher by the majority of students in all classes and by four of the six teachers. Furthermore, it suggests that it is worth to let come out students' pre-knowledge and share it with peers, as putting together individuals' point of views, within the class community, a wide range of ideas about the topic at hand can be pointed out. Comparison of process observations between C1 and C2 also shows that, during the following sessions, C2 students paid more attention when their peers were presenting the information they found. This could happen, because in C2, all the students of the class had to search for information about the same concept at the same time, while in C1, every small group dealt with a different concept and, when other groups were presenting, they were not familiar with the matter and their minds wandered easily. Of course, with the approach used in C2, less aspects of a topic can be afforded with the same amount of time, but on the other hand, students are likely to learn about everything but not only about the concept they are in charge as it can happen in C1 approach. About students' perception about PBL impacts on learning, students' impression in C2 is slightly better than in C1 (see Table 3).

Table 2

Students' Answers to Multiple Choice Questions About Engagement

Comparing with the lessons I'm used to, I think that with PBL method I've been:	All the classes (%)	Cluster C1 (%)	Cluster C2 (%)
less engaged	7.8	9.1	5.4
more engaged	51.5	42.4	67.6
engaged as usual	40.8	48.5	27.0

Table 3

Students' Answers to Multiple Choice Questions About Learning

Comparing with the traditional lessons, I think that PBL method allows to learn:	All the classes (%)	Cluster C1 (%)	Cluster C2 (%)
worse than usual	8.8	10.8	5.4
better than usual	53.9	52.3	56.8
as usual	37.3	36.9	37.8

In general, teachers' and the researcher's observations show that when students experience a PBL approach for the first time, they encounter some difficulties that are listed below. Students are not used to analyzing information and recognizing reliable sources; they are not used to summarizing the important information that they read in a text and often copy and paste entire documents; some students feel uncomfortable when they have to speak with other students; they are not used to trusting all of their fellows, and thus they often pay less attention when other students are speaking; during group work, some of them tend to do things not related with the assignment; they might have difficulties in dealing with a too complex scenario; they find themselves lost at the stage of studying for the final test.

Similar opinions are also reported by students in their answers to open-ended questions regarding what they

disliked (see Table 4). It is worth to note that the first answer is in favour of a more extensive use of PBL, and this is also confirmed by the higher percentage (76%) of students that would like to use the method more often.

Table 4

Students' Answers to Open Ended Question: "What Did You Dislike?"

Answers	Percentage (%)
That it lasts just few weeks	19.2
Too much homework to do	12.5
That it was not clear what we have to study at the end of the module	11.5
Searching for information	10.6
The topic	7.7
Working in group as not everyone works	6.7
Presenting to and discussing with my fellows	3.8

Positive impressions given by students are reported in Table 5. We like pointing out that students that appreciated topic related to the environmental issue are more than those that did not like it. Moreover, several answers show that students appreciate when they are given more freedom and responsibility during discussions, information retrieval, and, definitely the learning process.

Table 5

Students' Answers to Open Ended Question: "What Did You Like?"

Answers	Percentage (%)
The higher engagement and participation of students during lessons	29.8
Working in group	26.9
Dealing with a topic related to everyday life	22.1
Studying using other sources and not only on the textbook	22.1
Being able to discuss among students and with the teacher	14.4
Comparing information retrieved at home with my fellows	11.5
That this method allow to study in depth the topic at hand	8.7
The higher autonomy and responsibility given to students	5.8

Eventually, we report some of the most rewarding free comments given by students:

“It has been one of the science modules I enjoyed more”;

“More interesting, less boring, it provides scope for inventiveness”;

“I'd like to use this method always, because it makes me study in a better way”;

“It makes me think about and understand better what I was studying”.

About the possibility to use PBL in secondary school, all of the six teachers agree that it can be used to teach science concepts, and five of them think that it should be used during most of the school year, if the aim is also that students develop the related skills. Of course, the acquisition of these skills would increase the effectiveness of PBL for the learning of scientific contents. The obstacles pointed out for an extensive use of PBL are (between bracket the number of teachers who mention it):

“The few time available and too many science contents to deal with in the curriculum” (6);

“Too many pupils in the same class make the tutorial process hard” (3);

"It requires more work to prepare the teaching/learning activities" (2);
"Parents could complain if the teacher doesn't explain the topics as usual" (1).

Teachers also affirm that in the final evaluation test, students' performance was within the average of each class. Four of them noted that students that usually got bad marks improved their results, and two of them that were some of the good students had lower marks than usual.

Conclusions and Implications

The ICP/PBL approach could be used to integrate environmental issues with curricular topics, but further experimental research should be done with different science topics, using the method extensively with the same students.

Both students and teachers seem to appreciate the method and would like to use it more often. Moreover, students' interest and engagement increase, and learning outcomes in terms of knowledge remain in the average of other modules developed with more traditional methods. Nevertheless, some difficulties are pointed out by students and teachers. Further researches have to be developed to find the best way to adapt the method to secondary schools with the aim of diminishing those difficulties.

Meanwhile, with this study, we can suggest some educational implications, which, of course, should also be investigated furthermore.

It is preferable to give students scenarios without information, which could make difficulties for them to use their pre-knowledge during the brain storming, and would increase students' participation in the first discussion.

During the learning process, it would be better if all the students look for information about the same aspect, so that the comparison and the discussion can be more participated in and there are fewer chances that some students learn only about some of the aspect of the entire topic.

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